Raw and Processed Oat Ingredients Lower Plasma Cholesterol in the Hamster

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ABSTRACT

The objective of this study was to determine if Oatrim, a product developed for use as a fat substitute, could also reduce plasma cholesterol due to its soluble dietary fiber content. Diets with soluble fiber contents of 0% (oat hydrolyzate) or 4.2–4.3% β-glucan from oat or Oatrim were fed to hamsters for 21 days. All oat derived diets reduced serum cholesterol compared to a control diet containing cellulose ($p \leq 0.05$). The available carbohydrate produced by the Oatrim process correlated inversely ($r^2=0.95$) with low density lipoprotein cholesterol concentration.

Key Words: Oatrim, oat bran, cholesterol, β-glucan, hamster

INTRODUCTION

MANY CONSUMERS SHOULD REDUCE FAT CALORIE INTAKE FROM the current 37–40% to below 30% (NIH, 1990; USDA, 1990) to reduce risk of atherosclerosis and other diseases that are related to diet. Oatrim, an ingredient developed to replace and reduce fat, may help to reduce fat calories (Inglett, 1991). Oatrim is produced from hydrolyzed oat flour and contains about 10% soluble fiber as β-glucan, compared to the 5–7% typically found in oats. β-glucan and other soluble dietary fibers (SDF) reduced plasma cholesterol in humans and animals (Anderson et al., 1990, Braaten. et al., 1994). In addition to caloric reduction, Oatrim may help to reduce plasma cholesterol.

The hypercholesterolemic hamster was selected to evaluate the effects of diets containing native and processed β-glucans, respectively, on plasma lipoprotein cholesterol levels. The cereal ingredients were formulated into diets that were high in fats, saturated fats, and cholesterol. Male hamsters and humans respond similarly to this type of diet by increasing plasma cholesterol levels (Spady et al., 1993). Our objectives were to determine if dietary supplementation with Oatrim affects plasma cholesterol in the hypercholesterolemic hamster model and to relate the polymer characteristics of β-glucans in oat products to their effects in lowering plasma cholesterol.

MATERIALS & METHODS

Animals and diets

Thirty male golden Syrian hamsters (Sasco, Omaha, NE) initial weight 34 to 41g, were fed a powdered stock diet (Rodent Lab Chow 5001, Purina Mills, St. Louis, MO) for 7 days. The animals were placed in individual wire-bottom cages in a room kept at 20–22°C, 60% rh and 12-h light and dark cycle. Following the initial 7-day period, 6 animals were randomly assigned from a weight sorted list to each of 5 test diets (α-cellulose control and 4 oat derived). Food intake was measured two times each week and body weights were monitored once a week. After 21 days on treatment diets the animals were killed, blood was collected and analyzed for total cholesterol by the cholesterol oxidase method and lipoprotein cholesterol by size exclusion chromatography as reported (German et al., 1996). All animal procedures were approved by the Animal Care and Use Committee, Western Regional Research Center, USDA, Albany, CA and conformed to the principles for care and use of laboratory animals" (Committee on Care and Use of Laboratory Animals, 1985).

Semi-purified diets (Table 1) contained 15% fat, 14.7% total dietary fiber (TDF), and 20% protein. Hexane defatted oat bran was repeatedly milled and sifted to produce β-glucan enriched oat flour (EOF) (Table 2) as described (Knuckles et al., 1992). Oatrim-10, Oatrim-5 and oat hydrolyzate were prepared as described (Inglett, 1991). The TDF of the Oatrim-5 diet was 4.65% compared to 14.7% in the other diets. The calculated caloric content of the diets ranged from 3.90 to 3.98 kcal/g dwb except for the Oatrim-5 diet which had a higher caloric content, 4.31 kcal/g dwb, due to its lower TDF content. The oat hydrolyzate diet and the cellulose control contained no ß-glucan. The remaining oat diets contained 4.21 to 4.35% β-glucan. Completed diets were analyzed for N, fat, ash and moisture by standard methods. Total dietary fiber content was determined by the method of Prosky et al. (1988), crude fat by official method 920.39C (AOAC, 1990), and nitrogen by combustion analysis (AACC 46-30,1995) using a LECO FP-428 (LECO, St. Joseph, MI). Total β-glucan content of oat bran flours was determined by the β-glucanase method (McCleary et al., 1985) as described (Knuckles et al., 1992).

β-glucan polymer characteristics were determined by size-exclusion chromatography and multiple angle laser light scattering analysis as reported (Knuckles et al., 1997). Samples of EOF oat ß-glucans were prepared for molecular weight characterization by extraction with 1N NaOH for 1h, pH adjustment to 11.5-12.0 and filtration (0.45 μm).

Differences between treatments were determined by Bonferroni's multiple range test at the 5% level.

RESULTS

OATRIM-10, -5 AND -HYDROLYZATE FEEDING RESULTED IN 36, 32 and 17% reduction in total plasma cholesterol (Total-C), respectively, and the EOF diet reduced Total-C 11% (Table 4) compared to the

Table 1—Diet Composition

Ingredient[a]	Control	Enriched oat flour	Oatrim 10	Oatrim 5	Oat hydrolysate
Coconut Oil, hydrogenated	100.0	100.0	100.0	100.0	100.0
Corn Oil 50	46.9	40.6	44.8	48.9	
Corn Starch	507.8	475.6	195.6	0.0	98.7
Casein 150.7	150.7	150.7	150.7	150.7	
Soy Protein	65.3	22.6	18.3	40.5	62.4
Cellulose147.4	75.6	100.3	0.0	143.1	
Oat flour/ product 0.0	149.4	395.7	673.4	401.3	
Vitamin mix	10.0	10.0	10.0	10.0	10.0
Mineral mix	35.0	35.0	35.0	35.0	35.0
DL-Methionine	3.0	3.0	3.0	3.0	3.0
Choline bitartrate3.0	3.0	3.0	3.0	3.0	
Cholesterol	2.0	2.0	2.0	2.0	2.0

*g/Kg diet on an as is basis. Ingredients: Hydrogenated coconut oil (#400950), corn oil (#401150), choline bitartrate (#400750), methionine (#402950), cholesterol (#400650), vitamin free casein (#400625), soy isolate (#4646), mineral mix (#260001), vitamin mix (#360001), and corn starch (#401200) were purchased from Dyets, Bethlehem, PA. Alpha cellulose (#900453) was purchased from ICN Biomedicals, (Cleveland, OH).

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Table 2—Oat Flour Ingredient Analysis

Component[a]	Enriched oat flour	Oatrim-10	Oatrim-5	Oat hydrolyzate
% Solids	91.95	95.01	93.4	93.66
Protein, Nx6.25	27.06	10.88	3.44	0.69
Fat	2.23	2.50	0.83	0.30
Ash	4.69	4.89	2.91	2.78
TDF	49.61	11.90	6.90	1.07
β-glucan	29.12	10.64	6.36	0.00

[a]% on dry weight basis, except % solids.

Table 3—Mean body weights, feed intakes and liver weights.

	Control	Oatrim 5	Oatrim 10	Oat Hydro	Enriched oat fraction
Final Wt	96.5±6.9	94.4±5.5	92.1±4.0	101.2±6.0	98.7±7.8
Wt Gain	32.8±6.8	30.9±5.3	28.6±5.2	37.2±6.4	34.7±4.7
Feed In	177±10.0	154±7.8*	156±6.2*	181±10	174±9.5
Efficiency, feed in/wt gain	5.6±1.0	5.1±0.8	5.6±0.9	4.9±0.6	5.1±0.5
Liver wt	5.3±0.6	4.8±0.8	4.4±0.5*	5.5±0.5	5.1±0.6

[a]Values are means ±_SD.
*Different from the control (P<0.05).

control. The Oatrim-10 and -5, and the EOF diets contained 4.21–4.35% β-glucan. The remaining diets contained no ß-glucan. Final weights, gains and feed efficiencies were not different from each other. However, feed intake was lower in the groups fed the Oatrim-5 and -10 diets compared to the control (Table 3). Mean liver weight of the group fed the Oatrim-10 diet, 4.41±0.45g, was lower than those of animals on all other diets including the control, 5.30±0.62g.

High density lipoprotein cholesterol (HDL-C) was the predominant form in the plasma. HDL-C was lower in plasma from animals fed the diets containing soluble dietary fiber (SDF), i.e. the EOF, Oatrim-5 and Oatrim-10 groups, than plasma from control fed animals (Table 4). Low density lipoprotein cholesterol (LDL-C) varied most with diet treatment and was 67% lower in the Oatrim-5 fed animals than in control animals. LDL cholesterol was found to be inversely correlated (r^2=0.95) with the available carbohydrate content of the diet from oats (Fig. 1). Very low density lipoprotein cholesterol (VLDL-C) of the group fed the Oatrim-10 diet was 54% lower than in to the controls.

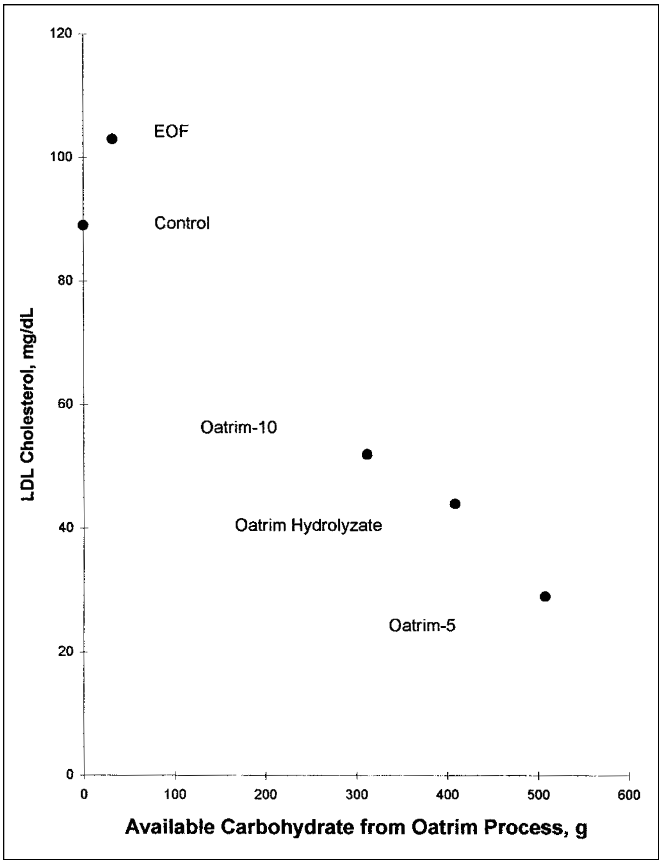

Fig. 1—Available carbohydrate from Oatrim process and LDL cholesterol. Dietary carbohydrate from Oatrim process, g/kg of diet, and resulting plasma low density lipoprotein (LDL) cholesterol are shown for hamsters fed diets containing dietary fiber from cellulose, enriched oat flour, Oatrim-10, Oatrim-5 and oat hydrolyzate.

Table 4—Plasma cholesterol distribution[a]

Diet treatment	VLDL mg/dL	LDL mg/dL	HDL mg/dL	Total mg/dL
Control	117±49a	89±42a	206±32a	413±94a
Enriched oat flour (EOF)	69±26ab	103±29a	153±15c	326±33ac
Oatrim-10	54±23b	52±11b	160±21bc	266±25b
Oatrim-5	90±36ab	29±4c	164±24bc	282±29c
Oat hydrolysate	106±32a	44±9b	193±20ab	343±46c

[a]Values are means ± SD. Means with the same letter in a column are not significantly different from each other (p<0.05).

Table 5—β-glucan Molecular Properties

Property	Enriched oat flour	Oatrim-10	Oatrim-5
Molecular wt. (M_w) g/mol	1.14×10^6	0.39×10^6	0.477×10^6 (major) 1.14×10^6 (minor)
Radius, nm	58.9±1.2	17.2±2.0	17.0±1.5 —
Polydispersity, (M_w/M_n)	1.346±0.084	2.259±0.044	1.020±0.032 (major) 1.545±0.023 (minor)

[a]Values are means ± SD. Means with the same letter in a column are not significantly different from each other (p<0.05).

DISCUSSION

TOTAL-C REDUCTION BY SDF HAS BEEN REPORTED IN BOTH humans and animals with dietary pectin, guar gum, methylcellulose, β-glucan and other soluble fibers (Anderson et al., 1990). SDF are linear carbohydrate polymers that form viscous aqueous solutions even at low concentrations. SDF viscosity has also been reported to be related to cholesterol reduction in hamsters fed diets containing a synthetic SDF, hydroxypropyl methylcellulose (Gallaher et al., 1993). Total-C was lower in hamsters fed high viscosity methylcellulose than in those fed low viscosity methylcellulose.

In our results, Total-C was lower in processed oat products containing SDF of lower molecular weight (Table 4). The viscosity of linear polymers is related to molecular weight. The M_w of β-glucan from Oatrim-10 and -5 were 66 and 58% lower, respectively, than β-glucan from EOF. Similar Mw reductions have been reported for β-glucan polymers in some breakfast cereals containing oat (Wood et al., 1991). In addition to size, processing may change the shape of β-glucan polymers. The ratio of β-glucan polymer M_w to volume calculated from the radii (Table 5) results in a ratio for the β-glucan from unprocessed oats of about 10 times larger than the ratio of the processed oat products. This ratio suggests that either the processed β-glucans were much more compact or dense, or that they were more spherical. Two β-glucan containing peaks were found in Oatrim-5 probably due to less complete β-glucan hydrolysis accompanying starch hydrolysis. A fraction with a high refractive index signal eluting after the β-glucan and presumed to be starch hydrolyzates was also present in the Oatrim and oat hydrolyzate samples. The stomach and intestines do not contain ß-glucanases; however, β-glucan degradation occurs in the digestive tract possibly due to the microflora of the gut and/or enzymes endogenous to cereals. The M_w of oat β-glucan from the intestinal tract of rats was lower than the M_w of dietary β-glucan (Wood et al., 1991). The M_w of barley β-glucan from hamster stomach and intestines were 100,000 daltons (unpublished results). Only small β-glucan fragments are present in the small intestine where lipids are absorbed into the body, suggesting that high molecular weight is not a necessary condition for plasma cholesterol lowering.

The reduction of LDL, VLDL and Total-C in animals fed the diet containing the Oatrim hydrolyzate was unexpected. This hydrolyzate was mainly carbohydrates from the enzymatic hydrolysis of starch used to prepare Oatrim. The available carbohydrate less cornstarch correlated inversely with LDL-C (Fig. 1). Since the hydrolyzate contained no β-glucans we hypothesized that other components such as phytosterols may be responsible for the cholesterol lowering. The effect of this non-β-glucan fraction on Total-C was as great as that of the fat extracted cell wall fraction (EOF diet).

CONCLUSIONS

WHILE PROCESSING SUBSTANTIALLY REDUCED THE MOLECULAR size of β-glucan polymers from oat, the hypocholesterolemic properties of oats were not affected and possibly were enhanced. Processed oat products may provide additional health benefits above and beyond fat replacement that would also reduce risk factors for cardiovascular disease.

REFERENCES

Anderson, J.W., Deakins, D.A., and Bridges, S.R. 1990. Soluble fiber: Hypocholesterolemic effects and proposed mechanisms. In *Dietary Fiber*, D. Kritchevsky, C. Bonfield, and J.W. Anderson (Ed.), p. 339-364. Plenum Press, New York.

American Association of Cereal Chemists. 1995. *Approved Methods*, 9th ed. VII. AACC, St. Paul, MN.

Association of Official Analytical Chemists. 1990. *Official Methods of Analysis*, 15th ed. The Association: Arlington, VA.

Braaten, J.T., Wood, P.J., Scott, F.W., Wolynetz, M.S., Lowe, M.K., Bradley-White, P., and Collins, M.W. 1994. Oat beta-glucan reduces blood cholesterol concentration in hypercholesterolemic subjects. Eur J. Clin. Nutr. 48: 465-474.

Committee on Care and Use of Laboratory Animals, Institute of Laboratory Animal Resources Commission on Life Sciences, National Research Council. 1985. *Guide for the care and use of laboratory animals.* Publ. 85-23(rev.) National Institutes of Health, Washington, DC.

Gallaher, D.D., Hassel, C.A., and Lee, K.J. 1993. Relationships between viscosity of hydroxypropyl methylcellulose and cholesterol in hamsters. J. Nutr. 123(10): 1732-1738.

German, J., Xu, R., Walzem, R., Kinsella, J., Nakamura, M., and Yokoyama, W. 1996. Effect of dietary fats and barley fiber on total cholesterol and lipoprotein cholesterol distribution in plasma of hamsters. Nutr. Res. 16: 1239-1249.

Inglett, G.E. 1991. Method of making a soluble dietary fiber composition from oats. U. S. Patent 4,996,063.

Knuckles, B.E., Chiu, M.M., and Betschart, A.A. 1992. Beta-glucan-enriched fractions from laboratory-scale dry milling and sieving of barley and oats. Cereal Chem. 69: 198-202.

Knuckles, B.E., Yokoyama, W.H., and Chiu, M.M. 1997. Molecular characterization of barley beta-glucans by size-exclusion chromatography with multiple-angle laser light scattering and other detectors. Cereal Chem. 74: 599-604.

McCleary, B.V. and Glennie-Holmes, M. 1985. Enzymatic quantification of (1-3),(1-4)-b-D-glucan in barley and malt. Inst. Brewing 91: 285-295.

NIH. 1990. National Cholesterol Education Program. Report of the Expert Panel on Population Strategies for Blood Cholesterol Reduction. U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health, National Heart, Lung and Blood Institute. NIH Publication No. 90-3046.

Prosky, L., Asp, N-G., Schweizer, T.F., Devries, J.W., and Furda, I. 1988. Determination of insoluble, soluble and total dietary fiber in foods and food products: Interlaboratory study. J. Assoc. Off. Anal. Chem. 71: 1017-1023.

Spady, D.K., Wollett, L.A., and Dietschy, J.M. 1993. Regulation of plasma LDL-cholesterol and fatty acids. Ann. Rev. Nutr. 13: 355-381.

U.S. Department of Agriculture and U.S. Department of Health and Human Services. 1990. Nutrition and your health: Dietary guidelines for Americans. U.S. Dept. of Agriculture and U.S. Dept of Health and Human Services; Home and Garden Bull. No. 232, USDA, Washington, DC.

Wood, P.J., Weisz, J., and Mahn, W. 1991. Molecular characterization of cereal ß-glucans. II. Size-exclusion chromatography for comparison of molecular weight. Cereal Chem. 68: 530-536.

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